Article AR2151

DOI: HTTPS://DOI.ORG/10.23910/1.2020.2151

International Journal of Bio-resource and Stress Management

December 2020

Crossref

Print ISSN 0976-3988
Online ISSN 0976-4038

IJBSM 2020, 11(6):548-557

Research Article *Natural Resource Management*

Influence of *In-situ* Soil Moisture Conservation Practices with Pusa Hydrogel on Physiological Parameters of Rainfed Cotton

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Citation: Ashraf et al., 2020. Influence of *In-situ* soil moisture conservation practices with Pusa hydrogel on Physiological Parameters of Rainfed Cotton. International Journal of Bio-resource and Stress Management 2020, 11(6), 548-557. HTTPS://DOI.ORG/10.23910/1.2020.2151.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

Abstract

The present study was undertaken to evaluate the impact of *in-situ* moisture conservation and stress management practices on crop growth indices and productivity of cotton under rainfed vertisol. The experiments were laid out at Regional Research Station, Aruppukottai, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu during *rabi* season (October-December) of 2016 and 2017 in split-plot design replicated thrice using cotton variety SVPR-2. The main plot treatments consisted of different *in-situ* moisture conservation measures *viz.,* Broad Bed and Furrows (I_1), Ridges and Furrows (I_2) and Compartmental Bunding (I_3). The subplot comprises with stress management practices viz., Soil application of pusa hydrogel @ 5 kg ha^{-1}(S_1) with different foliar spray of 1% KCl (S_2), 5% Kaolin (S_3), PPFM @ 500 ml ha^{-1} (S_4), Salicylic acid 100 ppm (S_5) and Control (S_6). The results revealed that treatment combination of broad bed and furrow and soil application of Pusa hydrogel @ 5 kg ha^{-1}+foliar spray of PPFM @ 500 ml ha^{-1} had recorded significantly higher crop growth indices like CGR, RGR, NAR, reduced proline content, higher values of relative leaf water content, chlorophyll SPAD values, yield attributes *viz*., sympodial branches plant^{-1}, number of bolls plant^{-1}, boll weight and seed cotton yield (1,786 kg ha^{-1}).

Keywords: BBF, pusa hydrogel, rainfed cotton

1. Introduction

India ranks first among the countries that practice rainfed agriculture both in terms of extent and value of production (Sharma, 2011). Rainfed regions in India contribute substantially towards food grain production including 44% of rice, 87% of coarse cereals (sorghum, pearl millet, maize), 85 per cent of food legumes, 72% of oilseeds, 65% of cotton, and 90% of minor millets. Overall, the rainfed areas produce 40 per cent of the food grains, support two-thirds of the livestock population and are critical to food security, equity and sustainability (Rao et al., 2015).

Globally, India ranks first in area (11.88 mha), accounting 30% of World acreage and 22% (35.1 million bales of lint) of the World cotton production with lint productivity of 568 kg ha^{-1}. Nearly 65% of the cotton crop is cultivated under rainfed conditions in the country (Anonymous, 2017). In Tamil Nadu, 0.2 mha is under cotton cultivation with the production of 0.6 m bales with and lint productivity is 620 kg ha^{-1} (Anonymous, 2014). India

Article History

RECEIVED in 03rd September 2020 RECEIVED in revised form 24th November 2020 ACCEPTED in final form 10th December 2020

has been the traditional home of cotton and their textiles. India has progressed substantially in improving both production and productivity of cotton, transforming from a net importer of cotton to become one among the largest exporters, shipping 6.9 million bales (2017-18) followed by USA.

Moisture stress in cotton adversely affect both vegetative growth and major metabolic processes like photosynthesis, stomatal conductance, relative water content, chlorophyll stability index and proline content which ultimately results in reduction of biomass production and yield of cotton (Kannan et al., 2019). The *in-situ* rain water conservation measures have benefits such as reducing runoff, increasing groundwater recharge and improving the nutrient status (Nuti et al., 2009). Soil and water conservation technologies are effective in reducing nutrient load in runoff thereby improving soil fertility and crop yields (Naudin et al., 2010). revealed that water harvesting reduced the runoff and erosion and increased infiltration and storage of water in the soil profile which delay the onset and occurrence of severe water stress thereby buffering the crop against damage caused by water deficits during dry periods (Nyamadzawo et al., 2013).

To improve the soil moisture availability by reducing the evaporation losses and retaining the moisture in the effective rooting zone. The soil application of superabsorbent polymers (SAPs) is found to be a promising methodology in rainfed areas. One such developed product is 'Pusa hydrogel,' which is the first successful indigenous semi-synthetic superabsorbent technology for conserving water and enhancing crop productivity and thereby increasing water use efficiency (Jain et al., 2017). This technology could be promising in terms of productivity improvement of rainfed crops and in combating the moisture stress in agriculture (Singh et al., 2018) and (Roy et al., 2019). To reduce transpiration losses, foliar application of nutrient formulations, growth regulators, antitranspirants *etc*. in cotton are being tried by many researchers. The work on biological formulation PPFM (pink pigmented facultative methylobacteria) on stress alleviation in rainfed crops is very limited, at the same time very promising results were documented by scientists. The PPFM, when used as foliar spray it releases osmoprotectants (sugars and alcohols) on the surface of the plants. This matrix helped to protect the plants from desiccation and high temperatures (Madhaiyan et al., 2006b). Whereas, the potassium as spray also enhanced drought tolerance in plants by mitigating harmful effects by increasing translocation and by maintaining water balance (Cakmak, 2005). Further, kaolin as an antitranspirant, applied as suspension to plant canopies and forms a film on leaves that increases reflection and reduces absorption of light (Singh et al., 2007). Salicylic acid is an endogenous growth regulator of phenolic nature, which participates in the regulation of physiological processes in order to mitigating the stress (Hayat Qaiser et al., 2010). Keeping this in view, an attempt was made to study the impact of *in-situ* moisture conservation and stress management practices on crop growth indices and productivity of cotton under rainfed agroecosystem.

2. Materials and Methods

Field experiments were was conducted at the Regional research station, Aruppukottai, Tamil Nadu Agricultural University, Tamil Nadu, India during *rabi* season of 2016 and 2017 (October-December) with the cotton crop using the test variety SVPR - 2. The experimental site comes under the Southern agro-climatic zone of Tamil Nadu and geographically situated at 9º 33'N latitude, 78º 05' E longitude, and at an altitude of 50 m above mean sea level. North-East Monsoon season was found more favourable in the Aruppukottai region since 42 percent of annual rainfall is being received during this monsoon season. The soil of the experimental fields was medium-deep, well-drained vertisol (*Type Chromusterts*). The soil is low in available nitrogen, low in available phosphorus and high in available potassium status. All packages of practices were carried out as per the recommendation of Anonymous, 2020.

The experiment was laid out in split-plot design, replicated thrice. The main plot treatments consisted of different *in-situ* moisture conservation measures *viz.,* Broad Bed and Furrows (I_1), Ridges and Furrows (I_2) and Compartmental Bunding (I_3). The subplot comprises with stress management practices *viz.,* Soil application of Pusa hydrogel @ 5 kg ha^{-1} (S_1), Soil application of pusa hydrogel @ 5 kg ha^{-1}+foliar spray of 1% KCl (S_2), Soil application of Pusa hydrogel @ 5 kg ha^{-1}+foliar spray of 5% Kaolin (S_3), Soil application of Pusa hydrogel @ 5 kg ha^{-1}+foliar spray of PPFM(pink pigmented facultative methylobacteria) @ 500 ml ha^{-1} (S_4), Soil application of Pusa hydrogel @ 5 kg ha^{-1}+foliar spray of Salicylic acid 100 ppm (S_5) and Control (S_6).

2.1. Method of PUSA gel application

The desired amount of hydrogel (5 kg ha^{-1}) was mixed with dry and fine sand of less than 0.25 mm size in 1:10 ratio, in order to distribute uniformly along the row. The sand mixed hydrogel was applied in line where the seed was sown (Narjary et al., 2013).

2.2. Time and method of foliar application for stress management

The data analysis for the probability occurrence of 30 years rainfall in a standard week showed that there is a possibility of consecutive dry spells during 45th and 50th standard meteorological weeks with more than 80 percent probability based on historical rainfall probability analysis by markov chain method. So, to avoid stress, foliar spray has given at 45th and 50th standard weeks for the years of study 2016 and 2017 based on historical rainfall probability analysis by Markov chain method to fix foliar spray application during the experimentation period

2.3. Proline content

The leaf proline accumulation was estimated as described by

Bates *et al.* (1973). Leaf sample (500 mg) was homogenized with 10 ml of 3% sulphosalicylic acid and centrifuged at 3000 rpm for 10 minutes. The supernatant solution was collected. Two ml of the aliquot was taken to which 2 ml of glacial acetic acid, 2 ml of 2.5% acid ninhydrin reagent and 2 ml of 6 M orthophosphoric acid were added. The final content was boiled over the water bath at 100°C for one hour for colour development. The content was cooled to room temperature and transferred into a seperating funnel to which 4 ml of toluence was added and stirred well for 20-30 seconds. Coloured layer was collected by separating the toluence layer and optical density (OD) was measured at 520 nm in a Spectrophotometer. Simultaneously, a series of standard solution with pure proline in the same way was maintained and the OD was recorded. The quantity of proline in the sample was calculated with reference to the standard curve and expressed in terms of µmol g FW^{-1}.

2.4. *Relative leaf water content*

The relative leaf water content was estimated by the method prescribed by Subbarao et al. (2000). Ten discs from the leaves of three hills were collected randomly in each treatment and weighed accurately up to fourth decimal on an electrically operated single pan analytical balance. This was considered as the fresh weight. The weighed leaf discs were allowed to float on distilled water in a Petri dish and allowed to absorb water for four hours. After four hours, the leaf discs were taken out and their surface was blotted gently and weighed. This was referred to as turgid weight. After drying these leaf discs in oven at 70ºC for 48 hours, the dry weight was recorded and designated as dry weight. The RLWC was calculated by the following formula.

RLWC (%)=(Fresh weight–Dry weight)/(Turgid weight–Dry weight)×100

2.5. *Chlorophyll content (SPAD reading)*

Chlorophyll content of leaves were recorded as described by Peng et al. (1993) using the chlorophyll meter (SPAD – 502, Soil Plant analysis Development Section, Minolta Camera Co. Ltd., Japan). The readings were recorded on the upper most fully expanded leaves in five randomly chosen plants at different growth stages. The average values were worked out and expressed as SPAD readings. Crop Growth Rate Watson (1958), Relative growth rate (RGR) (Enyi, 1962) and Net Assimilation Rate (NAR) (Enyi, 1962).

2.6. *Seed cotton yield*

The seed cotton yield was obtained from the net plot area was shade dried, weighed at each picking, and yields of all picking were added and then expressed in kilogram per hectare.

2.7. *Statistical analysis*

The data pertaining to the experiment were subjected to statistical analysis by Analysis of Variance (ANOVA) using AGRES (Data Entry Module for Agrees Statistical software version 3.01, 1994 Pascal Intl. Software Solutions). Differences between mean values were evaluated for significance using Least Significant Difference (LSD) at 5% probability level as suggested by (Gomez and Gomez, 1984).

3. Results and Discussion

3.1. *Growth indices of cotton*

Crop growth rate, Relative growth rate, and net assimilation rate were recorded at 30-60, 60-90 and 90-120 DAS. The *in-situ* moisture conservation practices and stress management measures exerted significant influence on the CGR, RGR and NAR of cotton at all stages of observation.

Physiological parameters like CGR, RGR and NAR were found to increase up to 90 DAS, and decrease thereafter. The increasing trend between 60-90 DAS may be due to the canopy achieves full interception of light, the variation in leaf area is a powerful determinant for differences in crop growth (Gifford and Jenkins, 1982). However, after canopy closure, photosynthetic CO_2 exchange per unit leaf area may become an important determinant of CGR, RGR and NAR. Therefore, it is assumed that a decline in growth parameters after flowering might be due to a reduction in CO_2 exchange per unit leaf area as a result of mutual shading. An increase in the net assimilation rate may be attributed to increased photosynthetic capacity.

As an *in-situ* moisture conservation measure, BBF recorded higher values of CGR, RGR and NAR at different stages of the crop in both the years, compared to other land configurations for *in-situ* moisture conservation. This might be due to higher soil moisture, which favors the nutrient uptake, which in turn reflected in higher LAI, specific leaf weight and dry matter production. A sufficient amount of soil moisture to meet the plant requirement under this treatment produced taller plants and higher LAI and consequently higher DMP, which led to higher physiological parameters. This result corroborates the findings of Nasrullah et al. (2011). Further, during the period of heavy rainfall BBF allow water to drain safely from the plots and thus avoid water congestion to the crop.

Regarding stress management practices, soil application of Pusa hydrogel @ 5 kg ha^{-1} + foliar spray of PPFM @ 500 ml ha^{-1} registered highest values of CGR, RGR, and NAR at different stages of crop in both the years of experimentation. CGR is influenced by LAI, photosynthetic rate, and leaf angle. A similar increase in CGR was observed in the soil treated with the superabsorbent polymer. Similar results also recorded by Yazdani et al. (2007) in soybean. SAPs can be efficiently used to reduce erosion, runoff, and soil losses, increasing the infiltration rates and the hydrophilic nature of the soil surface, which aids seed germination, emergence, and growth rate (Roqieh et al., 2013).

Further, PPFM favored the production of plant growth regulators, IAA, cytokinin, and GA, which resulted in diverse physiological effects in plants. It stimulates the division, extension and differentiation of plant cells, enhances plant growth parameters like CGR, RGR and NAR. Similar results were also reported by Sivakumar *et al*. (2017) (Table 1, 2 and 3).

3.2. Effect of in-situ moisture conservation and stress management practices on stress parameters

3.2.1. Relative Leaf water content (RLWC)

Maintenance of higher RLWC helps in sustaining the photosynthetic capacity of plants which ultimately contributes to better yield. Shortage of water supply in water limited environment affects growth and yield of plants by lowering tissue water status and turgor (Gadallah, 2000).

BBF system recorded higher RLWC compared to other *in-situ* moisture conservation measures. This might be due to higher infiltration and lower loss of rain water through runoff. This leads to high soil moisture content at the root zone which increased the plant water status. The results are in conformity with those of Selvaraju and Balasubramanian (2001) and Vivek and Bosu, (2014)

Regarding stress management practices, soil application of pusa hydrogel @ 5 kg ha^{-1} + foliar spray of PPFM @ 500 ml ha^{-1} registered the maximum RLWC values at all the stages of observation in both the years of experimentation. The superabsorbent polymer amendment increased the relative water content (RLWC) by storing and absorbing considerable water and reducing the negative effects of water shortage on plants. The superabsorbent polymer incorporation reduced the illeffects of excess moisture, reduced the electrolyte leakage and proline accumulation and also increased the leaf chlorophyll content.It collaborates with the findings of Mohammad and Fardin, (2012). In addition to this, PPFM spray released the osmoprotectants (sugars and alcohols) on the surface of the plants. This matrix helped to protect the plants from desiccation and high temperatures This was confirmed

Table 1: Effect of *in-situ* moisture conservation and Pusa hydrogel on crop growth rate (g m^{-2} day^{-1}) of rainfed cotton (pooled data of 2 years)

Treatments	30-60 DAS				60- 90 DAS				90-120 DAS			
	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
S_1	5.17	4.65	4.40	4.74	5.07	4.65	4.32	4.68	4.94	4.58	4.15	4.56
S_2	5.22	4.79	4.51	4.84	5.52	5.43	5.38	5.44	5.41	5.12	4.46	5.00
S_3	5.08	4.74	4.50	4.77	5.48	5.01	4.91	5.13	5.07	4.69	4.26	4.67
S_4	5.24	4.79	4.57	4.87	6.02	5.85	5.72	5.86	6.41	5.55	4.75	5.57
S_5	5.12	4.69	4.54	4.78	5.12	4.94	4.30	4.79	4.98	4.64	4.14	4.59
S_6	4.22	4.17	4.15	4.18	5.02	4.50	4.01	4.51	4.11	4.07	3.87	4.02
Mean	5.01	4.64	4.45		5.37	5.06	4.77		5.15	4.78	4.27	
	I	S	I at S	S at I	I	S	I at S	S at I	I	S	I at S	S at I
SEd±	0.10	0.12	0.21	0.20	0.09	0.17	0.22	0.24	0.15	0.12	0.24	0.20
CD(*p*=0.05)	0.28	0.24	NS	NS	0.25	0.35	NS	NS	0.41	0.24	NS	NS

Table 2: Effect of *in-situ* moisture conservation and stress management practices on relative growth rate (g g^{-1} day^{-1}) of rainfed cotton during *rabi* season (pooled data of 2 years)

Treatments	30-60 DAS				60- 90 DAS				90-120 DAS			
	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
S_1	0.0431	0.0415	0.0389	0.0412	0.0196	0.0170	0.0146	0.0171	0.0111	0.0104	0.0099	0.0105
S_2	0.0438	0.0412	0.0398	0.0416	0.0210	0.0196	0.0188	0.0198	0.0129	0.0117	0.0106	0.0117
S_3	0.0441	0.0418	0.0384	0.0414	0.0207	0.0193	0.0181	0.0194	0.0126	0.0109	0.0104	0.0113
S_4	0.0444	0.0415	0.0392	0.0417	0.0232	0.0211	0.0200	0.0214	0.0149	0.0131	0.0108	0.0129
S_5	0.0432	0.0409	0.0394	0.0412	0.0195	0.0185	0.0176	0.0185	0.0116	0.0106	0.0099	0.0107
S_6	0.0385	0.0376	0.0342	0.0368	0.0183	0.0147	0.0114	0.0148	0.0093	0.0088	0.0086	0.0089
Mean	0.0429	0.0408	0.0383		0.0204	0.0184	0.0168		0.0121	0.0109	0.0100	
	I	S	I at S	S at I	I	S	I at S	S at I	I	S	I at S	S at I
SEd±	0.0009	0.0011	0.0020	0.0019	0.0005	0.0004	0.0009	0.0007	0.0003	0.0003	0.0008	0.0005
CD(*p*=0.05)	0.0025	0.0023	NS	NS	0.0015	0.0009	NS	NS	0.0005	0.0004	NS	NS

Table 3: Effect of *in-situ* moisture conservation and stress management practices on net assimilation rate (mg cm^{-2} day^{-1}) of rainfed cotton during *rabi* season (pooled data of 2 years)

Treatments	30-60 DAS				60- 90 DAS				90-120 DAS			
	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
S_1	0.3762	0.3503	0.3338	0.3534	0.1550	0.1524	0.1491	0.1522	0.1041	0.1002	0.0974	0.1006
S_2	0.3880	0.3542	0.3319	0.3580	0.2329	0.2059	0.1741	0.2043	0.1155	0.1075	0.1032	0.1087
S_3	0.3861	0.3522	0.3284	0.3556	0.1996	0.1845	0.1700	0.1847	0.1089	0.1023	0.1011	0.1041
S_4	0.3990	0.3519	0.3222	0.3577	0.2623	0.2301	0.1953	0.2292	0.1378	0.1209	0.1052	0.1213
S_5	0.3790	0.3559	0.3325	0.3558	0.1842	0.1751	0.1671	0.1755	0.1063	0.1025	0.1021	0.1036
S_6	0.3295	0.3188	0.3090	0.3191	0.1385	0.1325	0.1273	0.1328	0.0997	0.0963	0.0945	0.0968
Mean	0.3763	0.3472	0.3263		0.1954	0.1801	0.1638		0.1121	0.1050	0.1006	
	I	S	I at S	S at I	I	S	I at S	S at I	I	S	I at S	S at I
SEd±	0.0095	0.0113	0.0201	0.0195	0.0067	0.0084	0.0149	0.0145	0.0032	0.0036	0.0065	0.0062
CD(*p*=0.05)	0.0264	0.0230	NS	NS	0.0187	0.0171	NS	NS	0.0089	0.0074	NS	NS

with the findings of (Madhaiyan et al., 2006a). Stress management practices also showed a significant influence on chlorophyll content. PPFM spray boosted the plant water status and enhanced the chlorophyll content in plants. Further, the gibberellic acid produced by PPFM, might have increased the chlorophyll content, photosynthetic activity by enhancing the number of stomata, stomatal conductance and plant water status. The similar findings also reported by Madhaiyan et al. (2004) (Table 4).

3.2.2. Leaf accumulated proline

Proline accumulation is believed to play vital role in plant stress tolerance. Proline accumulation in response to stress is widely reported and may play a role in stress adaptation within the cell (Gilbert et al., 1998). Proline was one of the key osmolytes contributing towards osmotic adjustments (Hare and Cress, 1997). Proline accumulation is believed to play vital role in plant stress tolerance. Moisture stress induces a significant decrease in metabolic factors such as decrease in chlorophyll content and enhanced accumulation of proline (Din et al., 2011). The accumulation of free proline in stressed plants has been found to be an adaptive mechanism for drought tolerance.

Table 4: Effect of *in-situ* moisture conservation and stress management practices on RLWC (%) of rainfed cotton during *rabi* season (pooled data of 2 years)

Treatments	30-60 DAS				60- 90 DAS				90-120 DAS			
	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
S_1	77.1	74.6	72.0	74.6	74.8	72.5	70.2	72.5	71.4	68.8	66.2	68.8
S_2	83.6	78.5	73.3	78.5	84.9	79.7	74.5	79.7	76.8	73.0	69.1	73.0
S_3	81.7	77.5	73.3	77.5	82.2	77.7	73.2	77.7	78.5	74.2	69.9	74.2
S_4	85.4	80.5	75.6	80.5	87.4	79.7	74.1	80.4	81.2	75.4	69.5	75.4
S_5	80.3	75.5	73.6	76.5	78.8	74.6	70.4	74.6	74.1	70.3	66.5	70.3
S_6	75.8	72.9	70.0	72.9	72.3	69.1	65.9	69.1	67.4	65.4	63.4	65.4
Mean	80.7	76.6	73.0		80.1	75.6	71.4		74.9	71.2	67.4	
	I	S	I at S	S at I	I	S	I at S	S at I	I	S	I at S	S at I
SEd±	1.58	1.41	3.53	3.46	1.78	2.29	4.03	3.96	1.46	1.28	3.22	3.15
CD(*p*=0.05)	4.04	3.98	NS	NS	4.98	4.67	NS	NS	4.08	3.76	NS	NS

In the present investigation, *in-situ* moisture conservation measures had a significant influence on the leaf accumulated proline content. When moisture stress increased the proline levels also increased. This was the possible reason to account for the accumulation and synthesis of proline to suppress the internal osmotic potential for maintain a positive gradient of water uptake under stress conditions. The compartmental bunding recorded higher levels of proline which was subjected to moisture stress often. In contrast, Minimum amount of proline levels was noticed with the broad bed and furrows system. The oxidation of proline under sufficient moisture conditions and subsequent conversion of proline to glutamic acid and other compounds were the possible reasons for low proline accumulation in BBF.

In the case of stress management practices, soil application of pusa hydrogel @ 5 kg ha^{-1} + foliar spray of PPFM @ 500 ml ha^{-1} registered lower proline level. This may due to water retention and available water capacity effectively increased with application of SAPs and its indicating the possible reduction in deep percolation losses in the soils leading to more available water within root zone to the plants for their extraction. The plants grown in hydrogel treated soil had more available water for its growth with higher stomatal conductance and higher leaf water potential for longer periods of time (Rehman et al., 2011).

Increased proline content of leaves indicates more moisture stressed of crops under rainfed condition. In the present study also moisture stressed treatments recorded higher proline levels.. The major reason for increase in proline concentration during moisture stress may be ascribed to lesser incorporation of continuously synthesized amino acid, proline during proline synthesis. The methanol is a natural product of plant metabolism, and it has now come to light that most plants also emit it from their leaves. PPFMs also responsible for the release of utilize methanol might play a role in the generation of increased quantities of ATP and NADH in the guard cells during photorespiration process and enhanced the sugar level of leaf. Thus it can maintain plant water status and reduces excess transpiration losses in the crops by osmotic adjustment (Madhaiyan et al., 2006b). With the help of PPFM, cytokinin which stops chlorophyllase enzyme synthesis which leads to less amount of chlorophyll content of the leaf retarded. Which can able capture of more amount sunlight which used for more photosynthetic efficiency (Madhaiyan et al., 2004) (Table 5).

Table 5: Effect of *in-situ* moisture conservation and stress management practices on leaf accumulated proline (µmol g^{-1} FW) of rainfed cotton during *rabi* season (pooled data of 2 years)

Treatments	70 DAS				90 DAS				105 DAS			
	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
S_1	6.30	8.25	10.20	8.25	8.14	10.15	12.17	10.15	8.02	10.39	12.76	10.39
S_2	5.35	6.10	6.60	6.02	6.67	7.55	8.24	7.49	6.67	8.83	11.00	8.83
S_3	5.50	6.25	8.40	6.72	6.97	7.77	9.58	8.11	6.90	9.50	11.65	9.35
S_4	4.12	5.36	6.60	5.36	5.95	6.96	7.87	6.93	6.30	8.73	11.10	8.71
S_5	6.20	7.65	9.10	7.65	7.48	9.11	10.73	9.11	7.40	9.60	11.80	9.60
S_6	7.00	9.15	11.30	9.15	10.40	11.83	13.27	11.83	8.47	11.89	15.30	11.89
Mean	5.75	7.13	8.70		7.60	8.90	10.31		7.29	9.82	12.27	
	I	S	I at S	S at I	I	S	I at S	S at I	I	S	I at S	S at I
SEd±	0.21	0.32	0.55	0.56	0.16	0.24	0.41	0.41	0.20	0.24	0.43	0.42
CD(p=0.05)	0.59	0.66	NS	NS	0.43	0.58	NS	NS	0.57	0.49	NS	NS

3.2.3. Leaf chlorophyll meter - SPAD readings

The chlorophyll meter - SPAD instantly measures chlorophyll content or “greenness” of plants. Chlorophyll meter- SPAD readings significantly varied with *in-situ* moisture conservation measures and stress management practices in both the years. Generally, there was progressive increase with advancement of crop growth upto flowering and declined towards maturity.

Adoption of BBF exhibited significantly higher chlorophyll SPAD values in leaf tissue at all growth stages during both the seasons of experimentation. Higher chlorophyll content of plant leaves is associated with better uptake of N which needs adequate moisture supply in the root zone. The higher root volume under broad bed and furrows system increased the solubility and mobility of nutrients and helped to absorb more nutrients which enhanced the chlorophyll synthesis. Similar findings was also reported by Johnkutty and Palaniappan (1995).

Stress management practices also showed a significant influence on chlorophyll content Regarding stress management practices, the maximum SPAD values were observed under soil application of pusa hydrogel @ 5 kg ha^{-1} at 60 DAS during both the 2016 and 2017. The superabsorbent polymer incorporation reduced the illeffects of excess moisture, reduced the electrolyte leakage and proline accumulation and also increased the leaf chlorophyll content. This was confirmed with the findings of Mohammad and Fardin (2012). In addition, PPFM spray boosted the plant water status and enhanced the chlorophyll content in plants. Further, the gibberellic acid produced by PPFM, might have increased the chlorophyll content, photosynthetic activity by enhancing the number of stomata and stomatal conductance. The similar findings also reported by Madhaiyan et al. (2004) (Table 6).

3.3. Effect of in-situ moisture conservation and stress management practices on yield attributes of cotton

The seed cotton yield is the manifestation of yield attributes *viz*., sympodial branches per plant, number of bolls plant^{-1}

Table 6: Effect of *in-situ* moisture conservation and stress management practices on chlorophyll SPAD values of rainfed cotton during *rabi* season (pooled data of 2 years)

Treatments	70 DAS				90 DAS				105 DAS			
	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean	I_1	I_2	I_3	Mean
S_1	35.3	32.5	31.5	33.1	36.3	34.9	33.4	34.9	39.5	37.2	36.5	37.7
S_2	35.1	32.3	32.2	33.2	41.4	38.8	36.2	38.8	44.2	41.5	39.5	41.7
S_3	35.1	33.2	31.0	33.1	38.3	36.4	34.4	36.4	42.7	40.2	38.4	40.4
S_4	36.7	32.1	31.4	33.4	43.7	40.1	36.5	40.1	45.8	43.2	40.6	43.2
S_5	35.8	32.9	32.1	33.6	38.1	35.3	32.4	35.3	39.9	38.5	38.1	38.8
S_6	32.7	30.2	29.0	30.6	33.0	32.2	31.5	32.2	37.7	36.2	36.0	36.6
Mean	35.1	32.2	31.2		38.5	36.3	34.1		41.6	39.5	38.2	
	I	S	I at S	S at I	I	S	I at S	S at I	I	S	I at S	S at I
SEd±	1.05	0.90	1.77	1.55	0.84	1.09	1.89	1.85	0.96	0.95	1.78	1.64
CD(p=0.05)	2.92	1.83	NS	NS	2.32	2.22	NS	NS	2.67	1.93	NS	NS

and boll weight. All these yield parameters were significantly influenced by the *in-situ* moisture conservation and stress management practices.

The number of sympodial branches per plant was found to be was significantly higher with than the treatments. Due to increased and continuous availability of soil moisture under broad bed and furrows system, the growth was enhanced and consequently the number of sympodial branches increases. The higher number of bolls plant^{-1} was noticed under broad bed and furrows than the other moisture conservation methods. This might also be ascribed to higher retention of moisture in boll development stage and better aeration in rooting zone. This leads to more numbers of bolls productions. Similar results were also reported by Kuotsu et al. (2014). The adoption of BBF method recorded significantly higher boll weight compared to other *in-situ* moisture conserving land management practices. This may be due to increased DMP and better translocation of photosyntheates from source to sink and resulted in better development of bolls.

Among the stress management practices, soil application of pusa hydrogel @ 5 kg ha^{-1}+foliar spray of PPFM @ 500 ml ha^{-1} recorded higher number of sympodial branches plant^{-1}, bolls plant^{-1} and boll weight respectively over control. This might be due to application of superabsorbent polymers helped to alleviate drought stress through retention of more moisture in the rooting zone and increased number and weight of bolls. Further, foliar application of PPFM, increased total dry matter production of cotton due to better translocation of photosyntheates and led to better boll development and boll weight. These results are in conformity with observations made by Madhaiyan et al. (2006 b) (Table 7).

3.4. Effect of in-situ moisture conservation and stress management practices on Seed cotton yield

Yield is contributed by different yield parameters and any change in one parameter as influenced by an extraneous factor will alter the yield significantly. In the present study, the increase in seed cotton yield could be attributed to greater and consistent available soil moisture due to combined influence of BBF, soil conditioner and foliar nutrition of PPFM increased that resulted in better crop growth rate and seed cotton yield.

Among the *in-situ* moisture conservation measure, BBF recorded a significantly higher seed cotton yield. The yield increases under BBF as compared to compartmental bunding. The broad bed furrow system significantly influenced the seed cotton yield as compared to other land configuration. Increment in seed cotton yield is due to more soil moisture availability at the root zone which favored better crop growth rate and higher translocation leading to the production of larger leaf area which was responsible for harvesting more solar energy. This coupled with higher stomatal conductance and transpiration rate resulted in the accumulation of more photosynthates and, ultimately, the seed cotton yield. This is in similarity to the findings of Muralidaran and Solaimalai (2005).

Higher seed cotton yield was realized with a complementary alliance of *in-situ* moisture conservation measures with stress management practices in the present study. Significant influence by stress management practices also recorded with soil application of Pusa hydrogel @ 5 kg ha^{-1}+foliar spray of PPFM @ 500 ml ha^{-1} which registered higher seed cotton yield This was followed by soil application of Pusa hydrogel @ 5 kg ha^{-1}+foliar spray of 1% KCl (S_2). The lower seed cotton yield was recorded under control (S_6), respectively. This may be due to the increased growth indices, could be because of sufficient availability of soil moisture and better nutrients availability due to superabsorbent polymer application under water stress condition, which in turn leads to better translocation of water, nutrients and photoassimilates and finally better plant development. Similar findings were also reported by El-Hady et al. (1981) under water stress conditions. The increase in the seed cotton yield because of

Table 7: Effect of *insitu* moisture conservation and stress management practices on sympodia plant^{-1}, boll weight (g boll^{-1}), bolls plant^{-1} and seed cotton yield (kg ha^{-1}) of rainfed cotton during *rabi* season (pooled data of 2 years)

Treatments	Sympodia Plant^{-1}	Boll weight (g boll^{-1})	Bolls Plant^{-1}	Seed cotton yield (kg ha^{-1})
In-situ moisture conservation				
Broad bed and furrows	13.0	3.76	18.1	1,590
Ridges and furrows	11.9	3.53	15.8	1,467
Compartmental bunding	10.9	3.36	13.5	1,350
SEd	0.2	0.10	0.6	32
CD(p=0.05)	0.5	0.24	1.6	117
Stress management practices				
Soil application of pusa hydrogel @ 5 kg ha^{-1}	11.3	3.42	13.7	1,376
Soil application of pusa hydrogel @ 5 kg ha^{-1}+foliar spray of 1% KCl	12.4	3.71	19.0	1,580
Soil application of pusa hydrogel @ 5 kg ha^{-1}+foliar spray of 5% Kaolin	12.2	3.50	16.7	1,485
Soil application of pusa hydrogel @ 5 kg ha^{-1}+foliar spray of PPFM @ 500 ml ha^{-1}	13.2	3.85	20.8	1,786
Soil application of pusa hydrogel @ 5 kg ha^{-1}+foliar spray of Salicylic acid 100 ppm	12.0	3.48	15.2	1,476
Control		3.31	9.4	1,109
SEd±	0.3	0.11	0.6	48
CD(p=0.05)	0.6	0.16	1.2	100

the several factors such as the release of growth-promoting substances like auxins, particularly indole-3-acetic acid (IAA) and indole-3-pyruvic acid, zeatin, zeatinriboside, proliferation of beneficial organisms in the phyllosphere and reacted cytokinins by methylotrophs has been reported as the factors that enhance plant growth of crops, the increase in the vegetative growth of the plant attributed to the increase in the yield of a crop. The foliar application of PPFM @ 500 ml ha^{-1} maintained physiological activity during stress period and thereby overcoming the water stress which ultimately resulted in increased the seed yield of cotton. From the above discussion, it could be concluded that foliar application of PPFM favorably influenced the seed cotton yield.

4. Conclusion

The crop grown under broad bed and furrows combined with foliar application of PPFM spray at 500 ml ha^{-1} recorded higher crop growth indices like CGR (5.57 g m^2 day^1), RGR (0.0129 g g^1 day^1), NAR (0.1213 mg cm^{-2} day^{-1}), reduced proline content (8.71 µmol g^{-1} FW), higher values of relative leaf water content (75.4 %), chlorophyll SPAD values (43.2) and seed cotton yield (1,786 kg ha^{-1}).

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